[Translator's Note: The German abstract and some text could not be translated due to the poor legibility of the copy.]

Road dust change absorption of solar radiation by plant leaves

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1. Introduction and Overview

The leaves of plants must fulfill their biological functions over long periods of time. Environmental factors affecting them must vary within limits that cannot always be precisely defined without causing physiological and anatomical changes; for example, they can influence photosynthesis to such a degree, that the net production over integrated over a growth cycle sinks to below zero. In addition to the environmental factors that act directly by way of biochemical processes that determine gas exchanges and nutrient supply, microclimatic factors in interaction with anatomical, morphological, and geometric size of the leaves bring about the leaf temperature. This affects the metabolism of the leave by way of photosynthesis, which is very sensitively affected by temperature. The influence of the individual environmental factors on the magnitude of the leaf temperature can be determined by means of the energy balance of the leaf. An overview of the methods used can be found in Eller [1]. The composition of the radiation balance produces the greatest energy fluxes and is consequently of first level significance for temperature control and regulation of the leaf temperature in the plant; in addition, radiation energy can be transformed in the photosynthetic process in the leaf directly into chemically bound energy.

A portion of the radiation energy of all wavelengths impinging upon the leaf (upper surface and lower surface) is reflected by the leaf surface; another portion is absorbed into the leaf, while the rest exits the leaf as transmitted radiation. This portion can vary very significantly depending on the wavelength of the radiation, as can be seen in Figure 1 for the average spectral absorption at a mesomorphic leaf. Extensive spectra of the leaves of various plant species can be found in Gates [2]. One differentiates (Fig. 1) the radiation ranges II: visible radiation (400 to 750 nm); II: short wave infrared I (750 to 1350 nm); III. short wave infrared II (1350 to 3000 nm), and IV: middle and long wave infrared (3000 to 60,000 nm). The radiation below 400 nm (ultraviolet or over 60 microns wavelength produce a relatively small energy flux and can generally be ignored.

According to Schulze [3] the energy portion of the global that is absorbed irradiation in the visible range is 32% and in the short wave infrared from 750 to 1350 nm wavelength 31%, while in the range below 400 nm it is 6 % and over 1350 nm 11%. These values vary somewhat depending on the height of the sun, water vapor, ozone, CO_2, and aerosol content of the air. In this case the radiation portions under 400 nm and over 1350 nm wave length are affected more significantly by these factors. Extensive spectral distributions for various air compositions and air masses can be found in Gates [4].

A comparison of the absorption curves with the global radiation impinging upon the surface demonstrates high absorption values in the range of visible radiation in which radiation absorption is accomplished by means of the plant pigment systems in the leaf; in the proximate range of the infrared, however, extremely low values are shown. These portions of the infrared radiation are not convertible in the pigment systems of the plant

and contribute solely to leaf warming. Low absorption rates for the infrared of the global radiation prevent the overheating of the leaf that would occur if the opposite were to be the case. At temperatures of approximately 45 °C and higher they are lethally injured by denaturization of the proteins and destruction of the enzyme systems.

Figure 1.   Spectral Absorptivity of mesomorphic leaves according to Eller [1]. Diagonal lines: Variation range of different species. A. Mean value of Absorptivity, I ... IV Wave length range (see text).

Wellenlänge =   Wave length

Figure 2.   Contaminated upper leaf surface of *Rhododendron catawbiense* [*sic*]

Figure 3.   Contaminated leaf [illegible text] of *Rhododendron catawbiense* [?]

2.   Statement of the Problem

In comparison to plants, mineral substances like dust and soil show a stabile or, with longer wave lengths, a slightly increasing absorption value at between 600 and 1350 nm [5]. If these materials lie on a leaf surface as dust emissions then it is certain that the optical properties of the total system leaf-plus-dust will produce some hybrid value from the optical properties of both components. Because in the normal situation the dust layer occurs only as a fine, only several microns thick dust layer (Fig. 2 and Fig. 3) additional energy portion of this layer contributes practically 100% to the warming of the substrate; that is, the leaf. The undersurface and the upper surface of the leaf are affected practically equally by the dust layer as shown in the scanning electron microscope shots (Fig. 2 and Fig. 3)
The question now arises to what extent such dust layers can influence the optical characteristics of the leaf system, which is very important in studies of the effect of dust emissions of heavy-traffic roadways on plants close to the road.

3.   Materials and Methods

The investigations were done in the months of January to March 1973 using leaves of the bushes of *Rhododendron catawbiense*. According to information provided by the Zurich traffic police, the peak traffic load on the Ramistraße in Zurich is 800 vehicles per hour (1972 Traffic Surveys). The bush is situated at 2.5 m distance from the traffic lane. Leaves were measured that were approximately 1 m above the ground and on exposed facing the traffic.
The spectral, diffuse reflectivity and transmissivity of the contaminated and previously treated leaves for the wave lengths range of 400 to 1350 nm was measured using a measurement device consisting of an integrating globe and a ISCO SR spectroradiometer as described by Eller [6]. From the reflectivity (r) and the transmissivity (t) the absorption (a) was determined using the relationship [illegible text]. The apparent optical properties for radiation impinging on the upper surface of the leaf (measurement on the upper surface of the leaf) was differentiated from those for radiation occurring on the undersurface of the leaf (measurement on the undersurface of the leaf). The optical

properties of the same, and thus of morphologically and anatomically identical leaves were taken as comparison values after the leaves after the dust had been removed from them using a cotton swab and distilled water.

4.   Discussion of the results

As can be seen in Figure 4, street dust deposits can be observed to create a considerable increase in the absorptivity for the infrared portion of the global irradiation which contrast with the small changes of the corresponding values for the visible radiation portion. An increased absorptivity in a very heavily contaminated leaf of an average of from 0.05 to 0.5; i.e., a factor of 10 in the wave length range from 750 t 1350 nm will necessarily have a powerful effect on the radiation balance of the leaf in the short wave range (0 to 3 micron wave length) and thus on the total energy balance.

If not only single measurements are made, then it is observed that with a larger number of samples, the absorptivity of the uncontaminated leave, on the basis of morphological and particularly on anatomical differences, albeit in part but relative also to the natural aging process of the leaves, is dispersed within relatively narrow limits, as shown in area G of Fig. 5. If the freshly cleaned leaves left on the plant after only five days of re-exposure are again measured, then they again show considerably increased absorptivity (curve G in Fig. 5). During this exposure period there was no precipitation and the adjacent street was dry. A comparison measurement fare an extender period of rainfall and wet snowfall demonstrates a self-cleaning effect (curve R in Fig. 5). The lower values of a clean leaf are, however, not attained. The underside of the leaf in *Rhododendrom catawbiense*, however, with its leaves that are only slightly off the horizontal, is not affected by this "natural cleaning." To what extent such "natural cleaning" at least prevents the catastrophic effects of the dust emissions on leaves can be demonstrated only by long-term studies.

If the changes in reflectivity, transmissivity and absorptivity are analyzed for the two instances of contaminated leaf and clean leaf then the relationships shown in Fig. 6 are demonstrated. The reflection at the leaf-dust-surface is reduced in comparison with the clean leaf surface. The reasons for this are the strong dispersion of the impinging radiation at the dust particles and the diffuse reflection of the radiation components from the leaf by the more or less shiny wax and cuticle layer of the leaf surface. The significantly increased absorption values can be explained by the fact that the impinging radiation is, on the one hand, absorbed by the mineral components of the dust and, on the other hand, also by the now increased impinging radiation is more intensely absorbed into the leaf cells due to the diffusion of the radiation by the dust particles. The portion of the transmitted radiation drops in the dust-covered leaf in relation to the increased absorption.

The chemical connection between the dust layer was not determined in the above situation. It can be assumed, however, that that the portion consisting of easily soluble salt crystals would not be considerable, which could be inferred from the relative effectiveness of the "natural cleaning" (Fig. 5). The measurements were of course done in a period of intense ice and snow control measures using salt.

5.   Conclusions

From the significantly increased absorptivity in the case of contamination with street dust an increase of the absorptivity of the leaf-dust-system for short wave infrared and thus an increase of the portion of the absorbed global radiation energy that is converted into heat must be concluded. This necessarily increases the energy input into the leaf, which can be compensated only with increased leaf temperature via the increased thermal intrinsic radiation and the convection on the energy output side of the leaf. The consequence of leaf contamination must be an elevated leaf temperature compared to the clean leaf. This could not be done in the present instance, because of the lack in the measurement instrument for leaf temperature measurement of contactless measurement radiometric thermometers. Corresponding measurements together with additional studies on other plants are planned. Still, after evaluation of the measurements, the assumption could not be disposed of, that in the extreme case, for example in intense irradiation and with disruption of water supply as can be the case in early spring, permanent damage by overheating of the leaves or leaf parts fully exposed to the global irradiation cannot be ruled out. The subject of the study was therefore further observed and in the following early summer, local damage could be observed on individual leaves. They could be interpreted only as burn damage due to overheating. These damages. The damage occurred only on those leaves exposed to the street up to a height of about 1 m above the ground. Higher level leaves or those which were less oriented to the street or those which were partially sheltered by other leaves did not exhibit any such damage. Fig. [illeg.] shows such partially damaged leaves.

Figure [illeg.]. Partially damaged leaves of *Rhododendron catawbiense*.

In addition to the question of overheating of the leaves by the alteration in the radiation balance in favor of higher absorption rates of the ... [article copy ends.